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Research Title:	TERAHERTZ FREQUENCY DETECTION AND IDENTIFICATION OF MATERIALS AND OBJECTS
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Institution:	RENSSELAER POLYTECHNIC INSTITUTE
Primary Investigator:	Dr. Xi Cheng Zhang
Invention Ind:	none
Project/Task:	2305D / X
Program Manager:	Gernot S. Pomrenke

Objective:

The objective of this conference is to bring together top NATO researchers from universities, industry and government laboratories who share a common interest in exploring and developing terahertz technologies for detection and identification of materials and objects. The grant applies primarily to supporting US participants to join this NATO Advanced Research Workshop to be held from July 6 to July 11 in Spiez, Switzerland.

Approach:

he workshop is by-invitation-only, with selected experts in the field of terahertz technologies from primarily NATO countries and an expert from Japan. The meeting includes oral presentations and discussions. To further stimulate interaction and discussion there will be a poster session to encourage the participants to present a poster of work from their group that is not highlighted in their talks. Primary themes or points of discussion will include: (i) new developments in THz devices (sources, detectors, amplifiers); (ii) progress in THz electronics and systems ; (iii) the science of THz/materials interactions; (iv) applications related to the maintenance of a safe and free society; and (v) secure communications.

Progress:

Year: 2007 **Month:** 05 **Final**

There is early demonstration of amplification of THz wave in laser induced air plasma in the workshop, however, solid state THz amplifiers, the workhorse of conventional electronics, still do not exist at THz frequencies but the workshop felt that devices based on QCL and SLED structures will soon be a practical possibility. For broadband generation it is likely that femtosecond pulsed fibre laser THz sources will replace the Ti:sapphire system because of their greater ruggednss together with the advantages of fibre delivery.

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14. ABSTRACT
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Final Report for NATO Advanced Research Workshop

Terahertz Frequency Detection and Identification of Materials and Objects

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Final Report

1. **Advanced Research Workshop**

   Title: **Terahertz Frequency Detection and Identification of Materials and Objects**

   Location : ABZ Conference Centre for the Swiss Meat Industry, Spiez, SWITZERLAND
   Dates : 07/07/07 – 11/07/06

2. **Co-directors**

   i) NATO-country Co-director

   Prof. X.-C. Zhang, Physics Department, Rensselaer Polytechnic Institute, Troy, NY 12180, USA

   ii) Partner-country Co-director

   Dr. Arunas Krotkus, Semiconductor Physics Institute, A. Gostauto 11, 2600, Vilnius, Lithuania

3. **Principal members of the Organizing Committee**

   Prof. Robert E Miles (Secretary), School of Electronic Engineering, University of Leeds, Leeds LS2 9JT, UK
   Dr. Heribert Eisele (Treasurer), School of Electronic Engineering, University of Leeds, Leeds LS2 9JT, UK

4. General Comments

Scientific Content

Terahertz science and technology, as applied to the aims of the workshop, were addressed under the following headings:- (i) Devices (ii) Interactions with Amorphous and Crystalline Materials (iii) Detection and Sensing and (iv) Systems.

(i) Devices: The Terahertz gap, usually taken as the frequency region from roughly 0.3 to 30 THz has now narrowed down to the range of 1 to 2.5 THz. Up to 1 THz, electronic devices such as multipliers and SLEDs (superlattice electron devices) are expected to deliver up to 1 mW of CW power and, although this has not yet been achieved, it is the target figure for the use of these devices in electronic circuits for example as local oscillators . Above 2.5 THz, Quantum Cascade Lasers (QCL) are already producing 10s of mWs of CW power, albeit at cryogenic temperatures. Steady progress is being made in raising the operational temperature towards a target of 200K where Peltier cooling becomes a practical possibility. Traditional devices such as backward wave oscillators can generate power in the THz gap but they are relatively fragile vacuum tube devices with short operational lifetime. Possibilities on the horizon include high power optoelectronic systems (OPO- optical parametric oscillators) and carbon nanotube transistors – oscillation at 50 THz is predicted.

Even there is early demonstration of amplification of THz wave in laser induced air plasma in the workshop, however, solid state THz amplifiers, the workhorse of conventional electronics, still do not exist at THz frequencies but the workshop felt that devices based on QCL and SLED structures will soon be a practical possibility. For broadband generation it is likely that femtosecond pulsed fibre laser THz sources will replace the Ti:sapphire system because of their greater ruggedness together with the advantages of fibre delivery.

(ii) Interactions with materials: THz absorption spectra for crystalline materials show characteristic peaks which can be used for identification purposes. A wide range of substances have been studied including the most common explosives and drugs of abuse. While the measurements taken at low temperatures exhibit sharp spectra, the characteristic peaks are still sufficiently well defined at room temperature to make substance identification possible.

By their very nature, amorphous materials (such as glasses, papers and polymers) do not exhibit any absorption peaks, even at low temperatures. Nevertheless, these materials are often used as containers for illicit substances so a knowledge of their absorption properties is essential. The results show that these properties vary significantly depending on the material.

(iii) Detection and Sensing: As mentioned in (ii) above, many materials of interest to the security and law enforcement agencies exhibit characteristic spectra at THz frequencies. This, combined with the ability of THz radiation to pass through many common materials such as, paper, clothing and plastics means that a knowledge of their absorption properties is essential in routine scanning for illicit materials.

THz frequency detection has the advantage of real time operation. Short range sample imaging is already in existence but stand-off detection, of say explosives, is more difficult. Requirements vary but distances up to 400m are often quoted. Generation at a distance using 4-wave mixing and detection is a possibility but because this involves high power laser beams it could only be used in certain situations. The remote deployment of THz systems ("smart dust") based on SLEDs or QCL is perhaps a more realistic possibility.

(iv) Systems: Whether CW single frequency or broadband pulsed systems are to be preferred is still a matter of debate that may well depend on the particular application. The introduction of compact sources is a pressing issue as is the development of a THz communications and signal processing technology comparable to that which already exists at lower frequencies. The meeting identified the need here to work with specialists in other relevant areas. This work would also require a catalogue of THz signatures. It was proposed that the "Spiez Protocol" should be formulated to ensure interacomparability and reproducibility of results, precise material information and standardisation of techniques.

A further suggestion was that a sub-group of the participants should get together to formulate a THz Technology Road Map.

5. Publication of results of the meeting

Title of Book : Terahertz Frequency Detection and Identification of Materials and Objects

Editor(s): (a) Prof. X-C Zhang
(b) Prof. R. E. Miles
(c) Dr. H. Eisele
(d) Prof. A. Krotkus

Publisher : Springer, Dordrecht, The Netherlands
Expected Date of Publication : January 2007

Main lectures/papers given during the workshop

1. THz Emission from Semiconductors Excited by Ultrafast Laser Pulses
2. Superlattice and other NDR Devices
3. Towards Superlattice THz Amplifiers and Lasers
4. Quantum cascade Lasers for the generation of THz waves
5. Tailoring the Emission of THz Quantum Cascade Lasers
6. Quantum Cascade Laser Applications
7. THz Spectroscopic Detection with Electronic Techniques
8. THz Time Domain Spectroscopy
9. THz Near-field Optics and Microscopy
10. Characterisation of Wire Waveguides for THz Pulses
11. System Requirements for a 0.3 – 3 THz Contraband Scanner
12. THz Generation by Multiplication
13. THz Biomolecular Sensing
14. Molecular and Organic Interactions
15. Interactions with Amorphous Materials
16. THz-Frequency Sensing Science & Electronic Technology
17. THz System Engineering for Real World Applications
18. Challenges to THz Counter Terrorism and Security Related Applications
19. THz Detection of Illegal Objects
20. THz Rays to Detect Drugs of Abuse
21. Development of Tagless Biosensors for Detecting Pathogen Presence
22. THz Spectroscopy for Chemical and Biological Applications
23. THz Communications – a 2020 vision.

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Prof. Arunas Krotkus	Semiconductor Physics Institute, A. Gostauto 11, 2600, Vilnius, LITHUANIA
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Prof. Giles Davies	School of Electronic Engineering, University of Leeds, Leeds LS2 9JT, UK
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